10-MWe Demonstration of Gas Suspension Absorption

Project completed

Participant

AirPol, Inc.

Additional Team Members

FLS miljo, Inc. (FLS)—technology owner

Tennessee Valley Authority—cofunder and site owner

Location

West Paducah, McCracken County, KY

Technology

FLS' Gas Suspension Absorption (GSA) system for flue gas desulfurization (FGD)

Plant Capacity/Production

10-MWe equivalent slipstream of flue gas from a 175-MWe wall-fired boiler

Coal

Western Kentucky bituminous: Peabody Martwick, 3.05% sulfur; Emerald Energy, 2.61% sulfur; Andalax, 3.06% sulfur; and Warrior Basin, 3.5% sulfur (used intermittently)

Project Funding

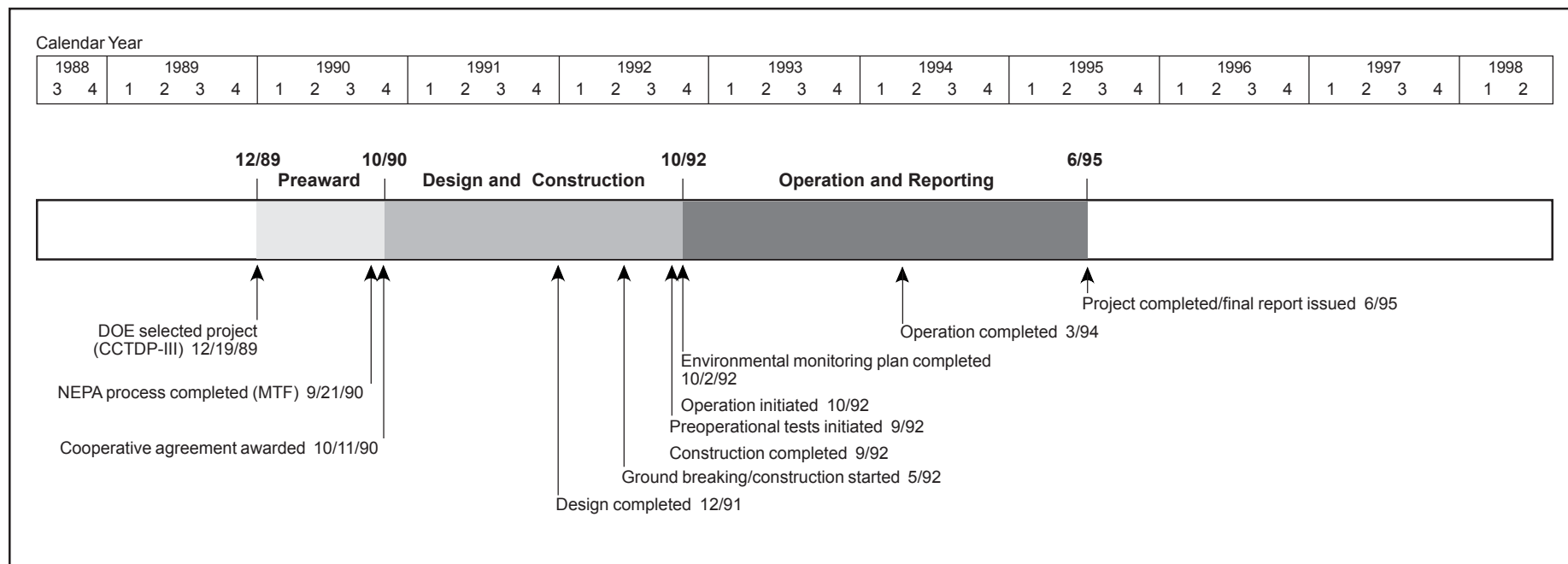|		
Total	$7,717,189	100%
DOE	2,315,259	30
Participant	5,401,930	70

Project Objective

To demonstrate the applicability of Gas Suspension Absorption as an economic option for achieving Phase II CAAA SO$_2$ compliance in pulverized coal-fired boilers using high-sulfur coal.
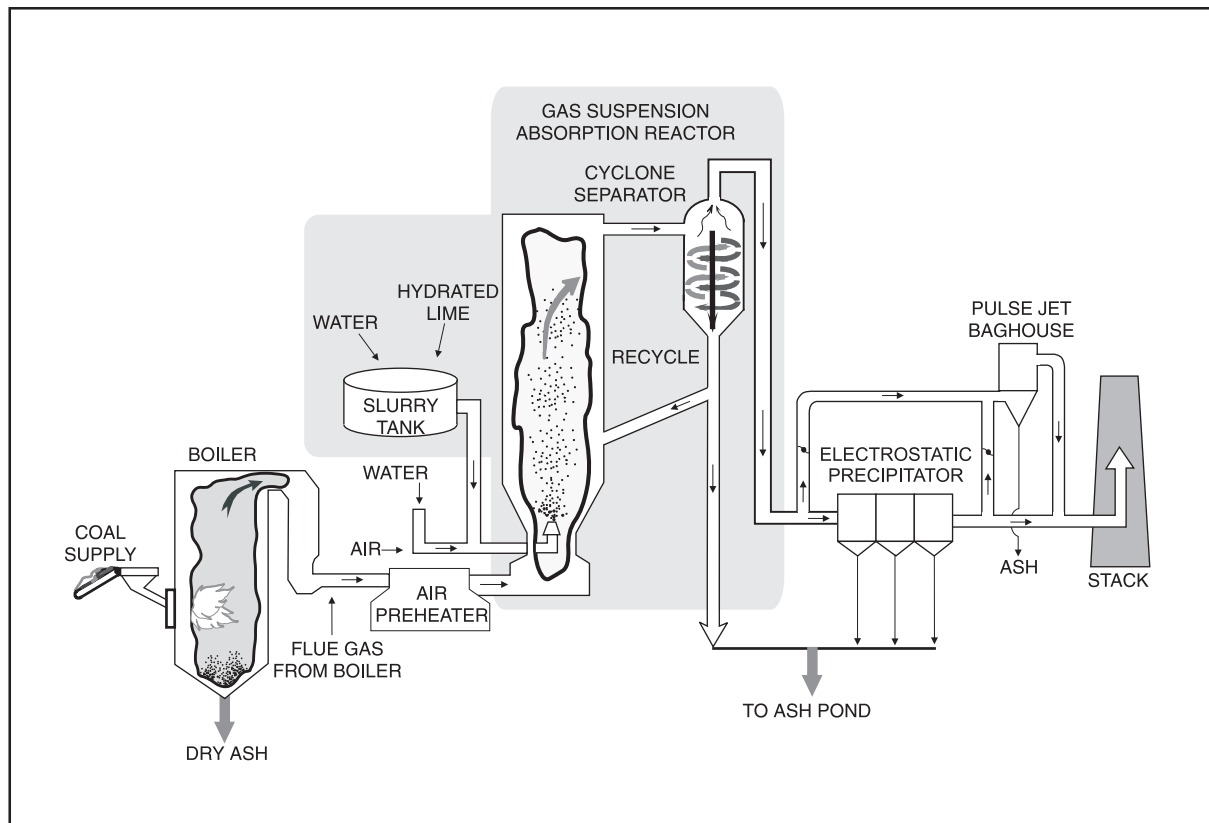
Technology/Project Description

The GSA system consists of a vertical reactor in which flue gas comes into contact with suspended solids consisting of lime, reaction products, and fly ash. About 99% of the solids are recycled to the reactor via a cyclone while the exit gas stream passes through an electrostatic precipitator (ESP) or pulse jet baghouse (PJBH) before being released to the atmosphere. The lime slurry, prepared from hydrated lime, is injected through a spray nozzle at the bottom of the reactor. The volume of lime slurry is regulated with a variable-speed pump controlled by the measurement of the acid content in the inlet and outlet gas streams. The dilution water added to the lime slurry is controlled by on-line measurements of the flue gas exit temperature.

A test program was structured to (1) optimize design of the GSA reactor for reduction of SO$_2$ emissions from boilers using high-sulfur coal, and (2) evaluate the environmental control capability, economic potential, and mechanical performance of GSA. A statistically designed parametric (factorial) test plan was developed involving six variables. Beyond evaluation of the basic GSA unit to control SO$_2$, air toxics control tests were conducted, and the effectiveness of GSA/ESP and GSA/PJBH combinations to control both SO$_2$ and particulates was tested. Factorial tests were followed by continuous runs to verify consistency of performance over time.

Calendar Year

1988		1989				1990				1991				1992				1993				1994				1995				1996				1997				1998	
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2

12/89 — **Preaward** — **10/90**
Design and Construction — **10/92**
Operation and Reporting — **6/95**

- DOE selected project (CCTDP-III) 12/19/89
- NEPA process completed (MTF) 9/21/90
- Cooperative agreement awarded 10/11/90
- Design completed 12/91
- Ground breaking/construction started 5/92
- Construction completed 9/92
- Preoperational tests initiated 9/92
- Operation initiated 10/92
- Environmental monitoring plan completed 10/2/92
- Operation completed 3/94
- Project completed/final report issued 6/95

Results Summary

Environmental

- Ca/S molar ratio had the greatest effect on SO_2 removal, with approach-to-saturation temperature next, followed closely by chloride content.
- GSA/ESP achieved
  - 90% sulfur capture at a Ca/S molar ratio of 1.3 with 8 °F approach-to-saturation and 0.02–0.04% chloride,
  - 90% sulfur capture at a Ca/S molar ratio of 1.4 with 18 °F approach-to-saturation and 0.12% chloride, and
  - 99.9+% average particulate removal efficiency.
- GSA/PJBH achieved
  - 96% sulfur capture at a Ca/S molar ratio of 1.4 with 18 °F approach-to-saturation and 0.12% chloride,
  - 3–5% increase in SO_2 reduction relative to GSA/ESP, and
  - 99.99+% average particulate removal efficiency.
- GSA/ESP and GSA/PJBH removed 98% of the hydrogen chloride (HCl), 96% of the hydrogen fluoride (HF), and 99% or more of most trace metals, except cadmium, antimony, mercury, and selenium. (GSA/PJBH removed 99+% of the selenium.)
- The solid by-product was usable as low-grade cement.

Operational

- GSA/ESP lime utilization averaged 66.1% and GSA/PJBH averaged 70.5%.
- The reactor achieved the same performance as a conventional spray dryer, but at one-quarter to one-third the size.
- GSA generated lower particulate loading than a conventional spray dryer, enabling compliance with a lower ESP efficiency.
- Special steels were not required in construction, and only a single spray nozzle is needed.
- High availability and reliability similar to other commercial applications were demonstrated.

Economic

- The capital cost for the GSA system is $149/kW (1990 constant dollars) with a spare module and $126/kW without a spare module, based on a 300-MWe plant using 2.6 percent sulfur coal.
- Levelized costs over a 15-year period are estimated at 10.91 mills/kWh (1990 constant dollars) with a spare module and 6.8 mills/kWh without a spare module.

Project Summary

The GSA has a capability of suspending a high concentration of solids, effectively drying the solids, and recirculating the solids at a high rate with precise control. This results in SO_2 control comparable to that of wet scrubbers and high lime utilization. The high concentration of solids provides the sorbent/SO_2 contact area. The drying enables low approach-to-saturation temperature and chloride usage. The rapid, precise, integral recycle system sustains the high solids concentration. The high lime utilization mitigates the largest operating cost (lime) and further reduces costs by reducing the amount of by-product generated. The GSA is distinguished from the average spray dryer by its modest size, simple means of introducing reagent to the reactor, direct means of recirculating unused lime, and low reagent consumption. Also, injected slurry coats recycled solids, not the walls, avoiding corrosion and enabling use of carbon steel in fabrication.

Environmental Performance

Exhibit 3-10 lists the six variables used in the factorial tests and the levels at which they were applied. Inlet flue gas temperature was held constant at 320 ºF. Factorial testing showed that lime stoichiometry had the greatest effect on SO_2 removal. Approach-to-saturation temperature was the next most important factor, followed closely by chloride levels. Although an approach-to-saturation temperature of 8 ºF was achieved without plugging the system, the test was conducted at a very low chloride level (0.04%). Because water evaporation rates decrease as chloride levels increase, an 18 ºF approach-to-saturation temperature was chosen for the higher 0.12% coal chloride level. Exhibit 3-11 summarizes key results from factorial testing.

A 28-day continuous run to evaluate the GSA/ESP configuration was made with bituminous coals averaging 2.7% sulfur, 0.12% chloride levels, and 18 ºF approach-to-saturation temperature. A subsequent 14-day continuous run to evaluate the GSA/PJBH configuration was performed under the same conditions as those of the 28-day run, except for adjustments in fly ash injection rate from 1.5–1.0 gr/ft³ (actual).

The 28-day run on the GSA/ESP system showed that the overall SO_2 removal efficiency averaged slightly more than 90%, very close to the set point of 91%, at an average Ca/S molar ratio of 1.40–1.45 (moles $Ca(OH)_2$/mole inlet SO_2). The system was able to adjust rapidly to the surge in inlet SO_2 caused by switching to 3.5% sulfur Warrior Basin coal for a week. Lime utilization averaged 66.1%. The particu-

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Exhibit 3-10
Variables and Levels Used in GSA Factorial Testing

Variable	Level
Approach-to-saturation temperature (°F)	8*, 18, and 28
Ca/S (moles $Ca(OH)_2$/mole inlet SO_2)	1.00 and 1.30
Fly ash loading (gr/ft³, actual)	0.50 and 2.0
Coal chloride level (%)	0.04 and 0.12
Flue gas flow rate (10³ scfm)	14 and 20
Recycle screw speed (rpm)	30 and 45

*8 °F was only run at the low coal chloride level.

Exhibit 3-11
GSA Factorial Testing Results

Note: All tests were conducted at a 320 °F inlet flue gas temperature.

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late removal efficiency averaged 99.9+% and emission rates were maintained below 0.015 lb/10⁶ Btu. The 14-day run on the GSA/PJBH system showed that the SO_2 removal efficiency averaged more than 96% at an average Ca/S molar ratio of 1.34–1.43 (moles $Ca(OH)_2$/mole inlet SO_2). Lime utilization averaged 70.5%. The particulate removal efficiency averaged 99.99+% and emission rates ranged from 0.001–0.003 lb/10⁶ Btu.
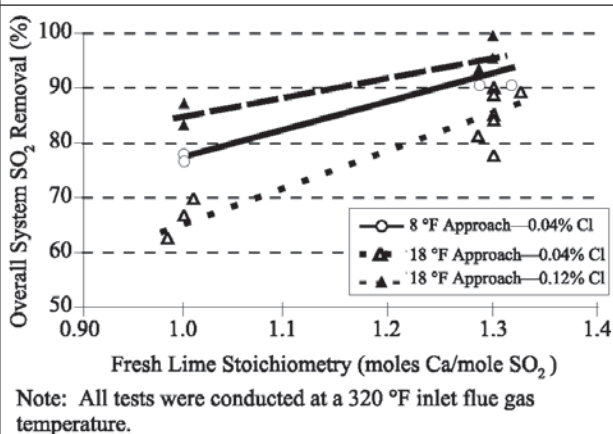
All air toxics tests were conducted with 2.7% sulfur, low-chloride coal with a 12 ºF approach-to-saturation temperature and a high fly ash loading of 2.0 gr/ft³ (actual). The GSA/ESP arrangement indicated average removal efficiencies of greater than 99% for arsenic, barium, chromium, lead, and vanadium; somewhat less for manganese; and less than 99% for antimony, cadmium, mercury, and selenium. The GSA/PJBH configuration showed 99+% removal efficiencies for arsenic, barium, chromium, lead, manganese, selenium, and vanadium; with cadmium removal much lower and mercury removal lower than that of the GSA/ESP system. The removal of HCl and HF was dependent upon the utilization of lime slurry and was relatively independent of particulate control configuration. Removal efficiencies were greater than 98% for HCl and 96% for HF.

Operational Performance

Because the GSA system has suspended recycle solids to provide a contact area for SO_2 capture, multiple high-pressure atomizer nozzles or high-speed rotary nozzles are not required to achieve uniform, fine droplet size. Also, recycle of solids is direct and avoids recycling material in the feed slurry, which would necessitate expensive abrasion-resistant materials in the atomizer(s).

The high heat and mass transfer characteristics of the GSA enable the GSA system to be significantly smaller than a conventional spray dryer for the same capacity—one-quarter to one-third the size. This makes retrofit feasible for space-confined plants and reduces installation cost. The GSA system slurry is sprayed on the recycled solids, not the reactor walls, avoiding direct wall contact and the need for corrosion-resistant alloy steels. Furthermore, the high concentration of rapidly moving solids scours the reactor walls and mitigates scaling. The GSA system generates a significantly lower dust loading than a

conventional spray dryer, 2–5 gr/ft^3 for GSA versus 6–10 gr/ft^3 for a spray dryer, thereby easing the burden on particulate controls. The GSA system produces a solid by-product containing very low moisture. This material contains both fly ash and unreacted lime. With the addition of water, the by-product undergoes a pozzuolanic reaction, essentially providing the characteristics of a low-grade cement.

Economic Performance

Using EPRI costing methods, which have been applied to 30 to 35 other FGD processes, economics were estimated for a moderately difficult retrofit of a 300-MWe boiler burning 2.6% sulfur coal. The design SO_2 removal efficiency was 90% at a lime feed rate equivalent to 1.30 moles of Ca per mole of inlet SO_2. Lime was assumed to be 2.8 times the cost of limestone. It was estimated that the capital cost was \$149/kW (1990\$) with three units at 50% capacity, and the levelized cost (15-year constant 1990\$) was 10.35 mills/kWh with three units at 50% capacity. With no spare capacity, the capital cost was estimated at \$126/kW and the levelized cost was estimated at 6.8 mills/kWh.

As shown in Exhibit 3-12, a cost comparison for a wet limestone scrubber with forced oxidation (WLFO) scrubber showed the capital and levelized costs to be \$216/kW and 13.04 mills/kWh, respectively. The capital cost listed in EPRI cost tables for a conventional spray dryer at 300 MWe and 2.6% sulfur coal was \$172/kW (1990\$). Also, because the GSA requires less power and has better lime utilization than a spray dryer, the GSA will have a lower operating cost.

Commercial Applications

The low capital cost, moderate operating cost, and high SO_2 capture efficiency make the GSA system particularly attractive as a CAAA compliance option for boilers in the 50- to 250-MWe range. Other major advantages include the modest space requirements comparable to duct injection systems; high availability/reliability owing to design simplicity; and low dust loading, minimizing particulate upgrade costs.

AirPol, Inc. successfully demonstrated the GSA system at TVA's Center for Emissions Research, located at TVA's Shawnee Plant.

Exhibit 3-12
Cost Comparison of GSA and WLFO

	Capital Cost (1990 $/kW)	Levelized Cost (mills/kWh)
GSA—3 units at 50% capacity	149	10.35
WLFO	216	13.04

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References

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SO_2 Removal Using Gas Suspension Absorption Technology. Topical Report No. 4. U.S. Department of Energy and AirPol, Inc. April 1995.

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